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INFLUENCE OF THE SUN'S SUPERCORONA ON THE VISIBLE POSITION AND SHAPE OF TRANSLUCENT RADIO SOURCES

by

N. A. Lotova

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INFLUENCE OF THE SUN'S SUPERCORONA ON THE VISIBLE POSITION AND SHAPE OF TRANSLUCENT RADIO SOURCES*

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by N. A. Lotova

SUMMARY

The simultaneous effect of radiowave scattering and refraction is considered in a two-component model of the solar corona upon the observed position of a discrete source, when the latter is eclipsed by the supercorona. Estimates are given of the distortion of the shape of the source at angular distances of the order of $(3 \div 10) R_\odot$ from the center of the Sun.

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A representation has been developed of the Sun's supercorona as a two-component model, consisting of the regular electron density component and of a statistically inhomogenous (or radial) component, with a relatively slow decrease of electron concentration, as the distance from the center of the Sun increases.

When investigating the Sun's supercorona by the translucence method using Crab-nebula types of radio sources, it is natural to assume that the 2nd component is the only one basically responsible for radiowave refraction. Inasmuch as the 1st component is characterized by a relatively rapid decrease of electron concentration as the distance from the Sun increases, one may assume that the effect of radiowave scattering will

* O VLIYANII SVERKHKORONY SOLNTSA NA VIDIMOYE POLOZHENIYE I FORMU PROSVECHIVAYUSHCHIKH RADIOISTOCHNIKOV.

prevail at great angular distances from the Sun's center ($r \sim 10 R_{\odot}$), while the refraction of waves can be disregarded. However, at distances $\sim(3 \div 10) R_{\odot}$, when both effects are significant, the problem of simultaneous effect of scattering and refraction must be solved: when a radio wave travels great distances, the latter effect may lead to the distortion of the visible shape of the radio source and to additional increase of scattering.

We shall examine for a preliminary estimate of the expected source shape distortion the case, when a refractive displacement is superimposed on the scattering pattern after the passage by the radio wave of a statistically inhomogenous medium containing only the second component of electron density.

The dependence of the mean electron concentration N_e on the distance to the center of the Sun is well approximated by the formula [2]:

$$N_e(\rho) = \frac{k_1}{\rho^{n_1}} + \frac{k_2}{\rho^{n_2}}, \tag{1}$$

where $k_1 = 0{,}9198 \cdot 10^7$, $k_2 = 0{,}6596 \cdot 10^5$, $n_1 = 2{,}9658$, $n_2 = 1{,}3517$, ρ is the distance from the center of the Sun expressed in solar radius' units. Let us compute the refraction R in that model of the solar corona.

The refractive index of the regular component of the supercorona may be written

$$\begin{gathered} n(\rho) = 1 - \Delta n, \qquad \Delta n \ll 1, \\ \Delta n = 4{,}47 \cdot 10^{-10} \lambda_м^2 \left(\frac{0{,}91 \cdot 10^7}{\rho^{2{,}96}} + \frac{0{,}65 \cdot 10^5}{\rho^{1{,}35}} \right), \end{gathered} \tag{2}$$

where $\lambda_м$ is the wavelength in meters. Let us consider a system of coordinates (z, r) with the origin at the center of the Sun, in which the plane electromagnetic wave propagates along the direction parallel to the axis z. If we neglect the rays' distortion, the refraction in the direction r ($\Delta n \ll 1$) will constitute

$$R = \lim_{\Delta r \to 0} \frac{\int\limits_{-\infty}^{\infty} n(r, z)\, dz - \int\limits_{-\infty}^{\infty} n(r + \Delta r, z)\, dz}{\Delta r} = \frac{\partial}{\partial r} \int\limits_{-\infty}^{\infty} \Delta n(r, z)\, dz. \tag{3}$$

Substituting (2) into (3) and differentiating over r, we shall obtain the expression

$$R(r,\ \lambda) = -\ 7{,}92\cdot10^{-10}\,\lambda_{\mu}^{2}\left(\frac{2{,}04\cdot10^{7}}{r^{2{,}96}}+\frac{0{,}89\cdot10^{6}}{r^{1{,}35}}\right), \qquad (4)$$

characterizing the dependence of the refraction on wavelength and distance to the center of the Sun. Note that in our problem the dependence $R(\lambda)$ is not quadratic, inasmuch as the quantity r (position of source's boundaries) depending upon the degree of scattering, itself function of λ, enters into the expression (4).

We shall utilize the values Φ_p of the angles of scattering, well known from the experiments of Crab nebula translucence experiments [3 – 4], and compiled in Table 1 hereafter, and we shall estimate the anticipated shift of the effective center of gravity of source's radiation, and also the distortion of its shape as function of r and λ*.

TABLE 1

	m	$\lambda(\mu)$	$\Phi_p(r=15)$	Φ_e
1954	1,64	3,5 5,8 7,5	1',05 2',88 4',81	6',5 7',0 7',5
1958	1,36	3,5 5,8 7,5	3',50 9',60 16',05	6',5 7',0 7',5
1963	1,15	3,5 5,8 7,5	3',32 9',10 15',20	6',5 7',0 7',5

The values of $\Phi_p(r)$ have been computed after the data of Table 1. At the same time, we utilized the representation of [3].

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* We utilized in the present work the values of the angles of scattering of references [3 – 4], related to the years 1954 and 1963, when the Sun was nearing the minimum period of its activity. It was shown in [4] that the effect of scattering depends upon the phase of solar activity. Evidently, such a dependence exists also for the first component characterizing the behavior of the mean concentration of electrons. However, the experiment by Blackwell [2] in 1954 was repeated by no one, and no other data exist in literature. That is why we shall use the characteristics of the first component referring to 1954 in all the numerical estimates.

$$\Phi_p = k/r^m. \tag{5}$$

For known $\Phi_p(r)$ we may compute the position of source's boundaries r_1, r_2 after radiowave scattering on the inhomogeneities of the solar corona, and the value of refraction can then be computed for the found r_1, r_2.* The values of $R_1(r_1)$, $R_2(r_2)$ determine the distortion of the visible shape of the source. The results of calculations are presented in Table 2, where $(R_2 - R_1)/2 = \Delta R/2$ is the shift of the effective emission center, and $\Delta R/2\sqrt{\Phi_0^2 + \Phi_p^2}$ characterizes the relative magnitude of shape distortion (Fig. 1).

TABLE 2

Year	λ(μ)	3 $r = 3$	4	5	6	7	8	9	10
1954 r.	3,5	10′37″	2′28″	52″	23″	12″	7″	4″	2″
	5,8	1°30′18″	14′52″	4′24″	1′41″	48″	26″	15″	10″
	7,5	7°39′30″	44′57″	11′47″	4′20″	1′55″	59″	33″	20″
1958 r.	3,5	22′54″	4′32″	1′26″	35″	27″	9″	5″	3″
	5,8	11°24′12″	43′16″	10′39″	3′51″	1′42″	51″	28″	16″
	7,5	—	4°10′26″	36′6″	11′31″	4′48″	2′20″	1′15″	44″
1963 r.	3,5	21′16″	4′20″	1′22″	29″	16″	9″	5″	3″
	5,8	9°10′34″	39′36″	9′54″	3′39″	1′37″	49″	27″	16″
	7,5	—	3°28′10″	33′27″	10′45″	4′36″	2′12″	1′11″	41″

The calculation shows that the accounting of the simultaneous influence of refraction and scattering of radiowaves leads to an insignificant displacement of the effective emission center in the region $r > 10\,R_\odot$; this effect becomes significant at distances $r \sim (3 \div 7)\,R_\odot$, and it is strongly dependent on λ. Fig. 1 illustrates that dependence; the solid curves are constructed after the data of Table 1 for 1954, and the dotted curves — for 1963. The relative influence of source's Φ_0 proper angular dimensions is more strongly manifest at small Φ_p. Assuming $\Phi_0 = 0$, one may obtain estimates for a point source of radio emission. These results allow, in principle, to determine by the observed source's shape distortion the mean gradients of electron concentration over fairly small angular distances from the center of the Sun; its proper angular dimensions can also be found the distortion of source's shape.

* Inasmuch as the refraction is maximum in the region of small s, that is, where the scattering angles are equal to $\Phi_p/\sqrt{2}$, we shall compute r_1, r_2 for a source with angular dimensions $\sqrt{\Phi_0^2 + \Phi_p^2/2}$.

In the works dealing with the statistical theory of radiowave scattering the constancy of the mean value of the index of refraction is usually postulated. However, in the case of a two-component model of Sun's supercorona it is necessary to take into account the small regular variations of the index of refraction, which, at small angular distances from the center of the Sun, have about the same order as the statistical fluctuations.

Let us consider the propagation of radiowaves in a statistically inhomogenous medium, in which the index of refraction sustains, alongside with small statistical fluctuations μ, smooth and regular variations of Δn:

$$n(r, z) = [1 - \Delta n(r, z)]\,[1 + \mu(r, z)], \quad \overline{\mu(r, z)} = 0, \qquad \mu \ll 1, \quad \Delta n \ll 1. \tag{6}$$

The regular variations of the index of refraction are so small, that we may neglect the refraction of the waves and consider only the scattering, which leads, on account of statistical fluctuations and regular variations of the index of refraction, to significant scattering effects at great distances. The correlation function of the index of refraction (6) is

$$\overline{n(r, z)\, n(r', z')} - \overline{n(r, z)}\;\overline{n(r', z')} = [1 - \Delta n(r, z)] \times [1 - \Delta n(r', z')]\,\overline{\mu(r, z)\,\mu(r', z')} = B_0[1 - \Delta n(r, z)] \times [1 - \Delta n(r', z')] \exp\left[-\frac{(r-r')^2 + (z-z')^2}{2l^2}\right], \tag{7}$$

where $B_0 = \overline{\mu^2}$, l is the average dimension of inhomogeneities.

Let us utilize expression for the scattering angle of radiowaves, (refer to [5]) :

$$\overline{\psi^2} = 4\psi(r, z) \int_0^\infty \rho''(0, s)\, ds, \qquad \psi(r, z) = \int_0^z \varphi(r, z)\, dz, \tag{8}$$

where the multiplier $\varphi(r, z)$ characterizes the small variations of refractive index' dispersion, and $\rho(r - r', z - z')$ are the variations, taking place at distances of the order of the correlation radius. From (2) and (7) we shall obtain the expression of the correlation function for a wave, propagating along the direction z by the distance r from the Sun's center. For sufficiently great z, we have

$$z = 2\sqrt{\rho^2 - r^2}$$

the dispersion of the scattering angle (8) in the medium with $\Delta n \sim \mu$ is

$$\overline{\Phi^2}(r) = 2\sqrt{2\pi}\, B_0 \frac{R_C}{l}\left[z - \frac{\lambda_м^2\, 0{,}164\cdot 10^{-1}}{r^{1{,}96}} - \frac{\lambda_м^2\, 0{,}558\cdot 10^{-2}}{r^{0{,}96}} + \dots\right]. \qquad (9)$$

The numerical computation of the ratio

$$\sqrt{\overline{\Phi^2(r)}/\overline{\Phi^2(r=15)}}$$

by the formula (9), at $l = \mathrm{const}$ allows to estimate the variations of the value of scattering as a consequence of regular variations of Δn. At $3 \leqslant r \leqslant 30$ it varies in the range 1.022 ÷ 0.915. Since in reality, the dimension of the inhomogeneities varies with the variation of r in the indicated intervals within a broad range ($10^2 \div 10^3$ times), the accounting of the dependence $l = l(r)$ will change the value of the computed ratio by $\sqrt{l(r=15)/l(r)}$ times.

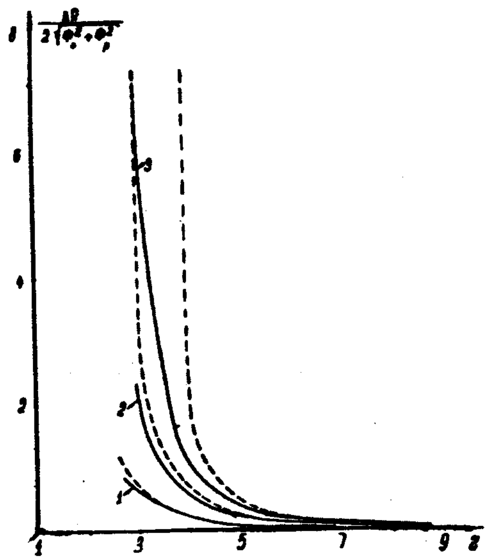

Fig. 1. - Dependence of the relative distortion of source's shape on the distance to Sun's center :

The comparison of the observed variations of the scattering angles with the corresponding computed values at $l = \mathrm{const.}$, allows to judge on the dimensions of the inhomogeneities as a function of the distance from the center of the Sun.

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**** THE END ****

Institute of Physics
of the
USSR Academy of Sc.

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